Such see-though features might also be useful for liquid-liquid contacting, such as might be done in liquid-liquid extraction.

Example 17

[0344] The effect of varying surface feature geometry and orientation was evaluated via CFD simulation of methane combustion in a large gap (0.047") main channel when operated with a high velocity (>80 m/s) for the reduction of emissions or the conversion of a dilute mixture oxygen and methane in nitrogen to very low levels of methane at the outlet.

[0345] An analysis was performed that compared methane combustion results over a 64 mm long exhaust reactor section, having surface features over 55 mm of that length, with 5700 ppm methane inlet at constant wall temperature of 870° C. for: a straight channel (no surface features), SFG-0-Cis-A-60° (surface features on two opposing walls aligned as a mirror image through a center plane and oriented at 60° relative to entrance plane (90° is parallel to the direction of net flow)), SFG-0-Cis-B-75° and SFG-5.1-Cis-B-60'. The SFG-5.1 geometry was the SFG-5 geometry which continually repeated the "check" surface feature in the same orientation. For each of these geometries, a 0.38 mm feature span and feature spacing, and a 0.51 mm feature depth was used. Each surface feature spanned the entire main channel width of 4.1 mm on each of the opposing walls. The SFG-0-Cis-A-60° had the lowest outlet methane ppm (262 ppm), followed by the SFG-5 Cis-B-60' (529 ppm), SFG-0-Cis-B-75' (545 ppm) and the straight channel (2844 ppm).

TABLE

Tabulated results for the 5700 ppm inlet methane combustion cases

Geometry	Conversion	Dry gas Methane ppm	Pressure drop [psid]
Straight channel 0.047" tall	50.5%	2844	0.76
CSF-0-Cis-B-75° 0.047" tall, 0.015" wide, 0.020" deep	90.5%	545	1.33
CSF-0-Cis-A-60° 0.047" tall, 0.015" wide, 0.020" deep	95.4%	262	1.80
CSFG-5.1-Cis-B-60° 0.047" tall, 0.015" wide, 0.020" deep	90.8%	529	1.60

[0346] The concentration of methane drops fairly linearly in the first few tenths of an inch of the reactor and then begins to decrease less significantly from 0.3 to 0.4 inches along the reactor length. In this region, the flowfield created by surface features is not yet at steady state and mixing is initiating within the reactor. After about 0.4 inches or so along the main channel length, the bulk flow begins to mix or rotate well within the reactor and the methane emissions drop again at a fairly steep rate. The flow is not laminar but moving and rotating in all directions thus new mass is brought into the centerline by advection not diffusion and thus the variation in centerline concentration. After about 2 inches the centerline concentration begins to get more uniform as the total conversion of methane reaches a high level. After 2.3 inches (where the surface features end) the centerline concentration is very low thus showing a very good conversion efficiency of the surface feature channel for this highly mass transfer limited problem.

[0347] The entrance length of 0.3 inch corresponds to roughly 10 surface features into the bulk flow path. The entrance length of roughly 10 features is less than the entrance length of a flat microchannel that exceeds 10 hydraulic diameter lengths into the microchannel. For this case with a gap of 1.19 mm, the hydraulic diameter exceeds 1.2 mm and thus more than 1.2 cm of total reactor length is required to achieve the fully developed laminar flow field. By contrast, the surface feature channel approaches the fully developed flow in 0.8 cm, in part because the size of the surface features (0.015 inch gap and span between surface features) is less than the microchannel gap of 0.047 inch. A shorter entrance length effect is anticipated with surface features that induce good mixing as opposed to a flat or smooth channel.

[0348] At elevated flow rates (>50 m/s) the SFG-0-Cis-A-45° features showed flow recirculation in the surface features. The angle of inclination of the SFG-0-Cis-A chevrons was increased from 45 degrees to 60° and 75°. The results showed two important things: The angle strongly affects mixing for higher velocity flow rates, and as the angle of the surface feature increases from 60 degress to 75 degrees, the cis-B orientation becomes slightly favored over the cis-A orientation. The best reaction performance for this case was observed with the cis-A orienation at 60 degrees angle. The best reaction performance case also had the highest pressure drop, attributed to the increased flow movement from the main channel to the active surface features.

Example 18

Residence Time Distribution Comparison

[0349] Residence time distribution (RTD) is an important performance indicator when designing a chemical reactor. The flows in microchannel reactors are, under most operating conditions, laminar. In a featureless microchannel reactor the fluid near the reactor walls is hard to push out of the reactor. This can potentially cause poor product selectivity and a hot spot for the exothermic reactions. In order to improve upon the RTD of a laminar flow reactor, surface features incorporated into channel walls can split the overall flow entering the reactor into many sub-flow streams without any external energy input. Surface features of opposite orientation on the opposite walls tend to hold the fluid longer.

[0350] In all cases, the use of surface features makes the flow profile closer to plug flow and thus gives a much narrower residence time distribution. The features selected in this study are SFG-0 at a 45 degree angle. In this example, the cis-A orientation gives the most flow rotation and the flow profile that is steepest and thus closest to true plug flow.

[0351] In a second comparison, a transient RTD evaluation was done to compare the RTD in a flat microchannel (1.02 mm by 4.1 mm, having no surface features) versus the same main channel with 0.25 mm deep recessed oblique grooves (pattern SFG-1). The hydrodynamics of the channel with surface feature was closer to plug flow. Laminar flow in a tube will show a classical Taylor-Aris dispersion in RTD resulting from the fast flow in the centerline (1.5× the